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"A method to enable assessment of growth and death of micro-organisms"
(Menetelmä mikro-organismin kasvun ja kuolemisen määrittämiseksi)

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A METHOD TO ENABLE ASSESSMENT OF GROWTH AND DEATH OF MICRO-ORGANISMS

This invention relates to a method to enable the assessment of growth and death of a micro-organism within a chosen time period in an environment of interest.

BACKGROUND OF THE INVENTION

When studying growth and death of a micro-organism under the influence of specific environments, e.g. production and storage environments that e.g. could or could not be refrigerated, or involving chemicals or matrixes, e.g. antibiotics, microbial toxins, heavy metals and serum complement, microbial cultures are most often incubated for hours or days. In these circumstances death and growth occur simultaneously. If additionally some of the cells lyse, e.g. when analysing the serum complement, it is difficult to know to what one should compare the amount of living cells at the end of the experiment. Convenient methods to determine the number of living cells, e.g. by measuring luciferase bioluminescence, are known but if no more information is available it is impossible to assess to what extent growth or/and death of the micro-organisms takes or has taken place.

Growth rates and death rates of micro-organisms in specific environments are of interest in many areas. Death rates and growth rates of micro-organisms and especially harmful and/or pathogenic micro-organisms are of importance in risk assessments of products of the pharmaceutical industry and products for human consumption with regard to there production, storage and distribution to the consumers. Knowledge of death and growth rates of micro-organisms are of particular importance in specific applications such as in the development of

antibiotics, disinfectants and bactericidal products or monitoring of sterilisation, disinfection and cleaning processes.

Reporter genes coding for luminescent or/and fluorescent products have been introduced to micro-organisms to enable the assessment of the quantity or survival of living micro-organisms. Even simultaneous use of luminescent and fluorescent markers have been used (Fratamico et al., Journal of Food Protection, Vol 50 No 10, 1997, 1167–1173). Luminescent and fluorescent markers have, however, only been used as markers for survival of micro-organisms and the use of two different markers within one micro-organism enabling the differentiation between growth and death rates has not been reported.

OBJECT AND SUMMARY OF THE INVENTION

The object of the present invention is to provide a method to enable the assessment of the growth and death of a micro-organism within a chosen time period in an environment of interest. The method is characterised in that

a) at least two reporter genes are introduced to said micro-organism, wherein the reporter genes used code for luminescent and/or fluorescent products and within said time period and environment at least two said products of the following are produced:

   i) an essentially stable product produced in a, within the environment of interest, essentially known proportion to the total amount of cells of said micro-organism that are or have been alive within said chosen time period,

   ii) a product present in said environment of interest in an essentially known proportion to the amount of cells alive at any moment within said chosen time period and

iii) an essentially stable product produced in a within the environment of interest essentially known proportion to the total amount of cells of the said micro-organism that have died within said chosen time period and

which products can be measured through their luminescence and/or fluorescence;

b) the said micro-organism is incubated within the environment of interest and said luminescence and/or fluorescence is detected after said chosen time periods and

c) the growth and death rate of the said micro-organism is assessed based on at least two of the following:

i) the known proportion of luminescence or fluorescence to the amount of cells alive after any said chosen time period,

ii) the known proportion of luminescence or fluorescence to the total amount of cells that are or have been alive within any said chosen time period and

iii) the known proportion of luminescence or fluorescence to the total amount of cells that have died within any said chosen time period.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows plasmid pGFP+luc* including genes for both GFP and firefly luciferase.

Figure 2a–2f shows the sequence of plasmid pGFP+luc*.

Figure 3 shows fluorescence during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of ethanol in the cell culture.

Figure 4 shows luminescence during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of ethanol in the cell culture.

Figure 5 shows the amount of living cells, i.e. colony forming units, according to plating during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of ethanol in the cell culture.

Figure 6 shows the percentage of live cells according to live/dead staining and flow cytometric analysis during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of ethanol in the cell culture.

Figure 7 shows fluorescence before and after incubation with serum complement during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of serum complement in the cell culture.

Figure 8 shows luminescence before and after incubation with serum complement during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of serum complement in the cell culture.

Figure 9 shows the percentage of living cells according to plating during growth phase of *E. coli* with plasmid pGFP+luc* at 30 °C as a function of the concentration of serum complement in the cell culture.

DETAILED DESCRIPTION OF THE INVENTION

The method according to the present invention can be used to assess the growth and death rate of a micro-organism within a chosen time period in any particular environment of interest. The method is applicable if two different marker genes can be introduced to the micro-organism that code for luminescent and/or fluorescent products, and the products of these fulfil at least two of the following three criteria:

a) a said luminescent product luminesces or said fluorescent product fluoresces in

an essentially known proportion to the amount of cells of said micro-organism alive within said chosen time period ;

b) a said luminescent product luminesces or said fluorescent product fluoresces in an essentially known proportion to the amount of cells of said micro-organism that are or have been alive within said chosen time period, and

c) a said luminescent product luminesces or said fluorescent product fluoresces in an essentially known proportion to the amount of cells of said micro-organism that have died within said chosen time period.

In the present application the concept "micro-organism" means any micro-organism into which marker genes can be introduced so, that they will function according to the invention. "Micro-organism" can therefore stand for bacteria, yeast or fungi.

The concept of "introducing a marker gene into a micro-organism" means any method by which a marker gene can be made to function within the micro-organism according to the invention. One way of introducing marker genes into micro-organism is by constructing a recombinant strain. This can be done by transforming a strain with a plasmid including the marker genes. An alternative way to introduce reporter genes to bacteria is to utilise transposable elements. In this technique, reporter genes are inserted between insertion sequences in a delivery plasmid. The plasmid is then introduced to a cell by e.g. conjugation of transformation, and once inside the cell, genes surrounded by the insertion sequences are integrated into bacterial chromosome. Integration is stable, i.e. there is no need for a selectable marker such as antibiotic resistance.

Assessment of the growth rate and death rate of a micro-organism can be of interest in many specific environments. Within pharmaceutical research the effect of different drugs and candidates for drugs, e.g. antibiotics, on the survival of pathogenic, but also the beneficial micro-organisms of the gut, is of interest. Thus

the ultimate interest is in the behaviour of these micro-organisms in a physiological environment affected by drugs.

Another vast area where the possibility of assessing growth and death rate of specific micro-organisms is of interest is that of production, processing, storage and distribution of all products for human consumption. In this area the behaviour of pathogenic or potentially harmful micro-organisms in the different environments of the life cycle of these products is of special interest and involves many different aspects such as the influence of temperature, humidity or light and the possible use of preservatives etc.

Additionally growth and death rates of micro-organisms can be of interest for environmental evaluations e.g. when evaluating the effect of emissions into the environment.

Luminescent or fluorescent products coded by reporter genes in different embodiments of this invention can vary as long as their proportion to either the total amount of cells alive, to cells that are or have been alive, or to cells that have died is essentially known. Growth and death rate can be assessed if two of the following: cells alive, cells that are or have been alive, or cells that have died can be determined. Thus luminescence and/or fluorescence measured can be e.g. of a product which is expressed e.g. constitutively or triggered by a specific phase (e.g. replication or death) of the lifecycle of each cell, is stable or labile or which luminescence or fluorescence is dependant on a factor that relates e.g. to a specific phase of the lifecycle of each cell. Depending on the individual characteristics of said product—how produced, stable or labile, possible dependence of its luminescence or fluorescence of said factors etc.— the measured luminescence or fluorescence can be in proportion to one of the three unknown of which two must be known to be able to assess the growth rate and death rate of said cells.

According to one specific embodiment of the invention assessment of the growth and death rate of an *Esherichia coli* strain under the influence of different chemicals or matrixes was enabled by constructing a recombinant strain, which expresses both luciferase and GFP. Alltogether the effect of a number of different chemicals and matrixes, such as $CdCl_2$, ethanol, the antibiotics chloramphenicol, rifampicin, and tetracyclin, as well as serum complement on said recombinant *E. coli* strain was tested and found applicable.

The invention will be described in more detail by the following study in which the growth rate and death rate of a recombinant *Esherichia coli* strain, which expresses both luciferase and GFP, is assessed under the influence of ethanol or serum complement.

Summary of the study

Genes for luciferase and green fluorescent protein have recently raised interest as reporter genes. Luciferase is an enzyme that produces luminescence in the presence of substrate luciferin, molecular oxygen and ATP. Green fluorescent protein (GFP), produces green fluorescence when excited with light. Many mutated forms of GFP have been introduced: some have different excitation and emission wavelenghts from the wild type and some mutants form more stable proteins at higher temperatures.

We constructed a recombinant strain of *E. coli*, which expresses both luciferase and GFP. In our construction we used a mutant of GFP which is more stable at temperatures over +30 °C and it matures quicker than the wild type. Luciferase was from North American firefly, *Photinus pyralis*.

The *E. coli* strain MC1061 was transformed with a plasmid including genes for both GFP and firefly luciferase. Figure 1 describes the plasmid in general and Figure 2 shows the sequence of the plasmid. Essential codings of the sequence are as follows:

lac promoter	95–199
GFP	289–1008
firefly luciferase	1044–2696
β-lactamase	3251–4111

In our construct, see Figure 1, the luciferase gene is situated next to the GFP gene and both genes are transcribed in the same direction. The transcription is started at the lac promoter in front of GFP. The lac promoter is constitutively active, because the MC1061 cells lack its repressor. The plasmid also has a gene for ampicillin resistance (beta-lactamase).

The transformed *E. coli* strain was propagated under the influence of different concentrations of ethanol or serum complement.

Methods

Growth conditions

One colony from a pure culture plate was inoculated in 5 ml of LB-medium with ampicillin (100 µg/ml) and grown at +37 °C in a shaker, 250 rpm, for about three hours. After that, the number of cells per millilitre was determined with flow cytometry by using fluorescent spherical latex particles as a reference. One million cells were then removed to an erlenmeyer with 50 ml of LB medium and ampicillin. The culture was grown over night in a shaker, 190 rpm, at room temperature to prevent the culture from growing into the stationary phase during the night. In the morning, the culture was transferred to and grown in a shaker, 330 rpm, until the stationary phase was reached or used after growth at +30 °C for about 1 h to study the influence ethanol or serum complement as described below.

Influence of chemicals on the propagation of *E. coli*

The culture obtained as described above was used to study the influence of ethanol or serum complement as follows:

Ethanol

Ethanol (Aa, Primalco Oy) was diluted into pure water to obtain concentrations of 50, 45, 25, 10, 5, 1 and 0 % of ethanol when 500 µl of said dilution was added to 500 µl of said culture in an eppendorf tube. The mixture was vortexed and incubated for 5 minutes before measuring fluorescence and luminescence. Live cells were again counted by plating and also by live/dead staining. In the live/dead protocol used the stain *cyto 9* stains all cells whereas propidium iodide stains only the dead cells. After staining, cells are passed through a flow cytometer, with which dead and live cells can be differentiated and their proportion determined. (Virta et al. (1998) Appl. Environ. Microbiol. 64: 515–519.)

Serum complement

The influence of serum complement on the said recombinant *E. coli* strain was studied using an incubation time of 90 min as described for a different recombinant *E. coli* strain used in Virta et al. (1998) Appl. Environ. Microbiol. 64: 515–519.

Fluorescence and luminescence measurements

The measurements were done with a combined fluoro- and luminometer, Fluoroscan Ascent FL, provided by Labsystems Ltd. (Helsinki, Finland). Cell growth was simultaneously followed with a flow cytometer.

For the measurements, 100 µl of bacterial culture was pipetted into the microtiter plate wells. Fluorescence was measured using 485 nm for excitation and 510 nm for emission. Measuring time was 20 ms. After the fluorescence measurement 100 µl of

luciferin in 0.1 M citric acid-sodium citrate buffer (pH 5.0) was dispensed into the wells and the plate was shaken for two minutes (shaking diameter 1 mm, 1 020 rpm), after which luminescence was recorded with a measuring time of 1000 ms.

Plating

Samples for plating were diluted 10^2 to 10^7 fold with 150 mM NaCl and plated onto L agar plates (L broth containing 1.6 % agar). Colonies were counted after overnight incubation at 37 °C.

Live/dead staining and Flow cytometric analysis

Bacteria from 1 000 µl of cell culture were used for live/dead staining and flow cytometric analysis using a LIVE/DEAD BacLight bacterial viability kit (catalogue no. L-7005) for microscopy and quantitative analysis obtained from Molecular Probes Europe (Leiden, The Netherlands) and Fluoresbrite beads (diameter, 1.8 µm) obtained from Polysciences Inc. (Warrington, Pa.) as described in Virta et al. (1998) Appl. Environ. Microbiol. 64: 515–519.

Results

When the cultures were transferred to +30 °C, the cells grew logarithmically for 1—4 hours depending on the initial cell concentration. Luminescence and fluorescence rose logarithmically and were essentially constant per cell. Thus cell number could be assessed based on luminescence or fluorescence.

When ethanol was added in different concentrations to the growth medium (see Figures 5 and 6) death was, after a very short incubation period of 5 min, more or less unsignificant at ethanol concentrations below 5 % and became more significant

with increasing ethanol concentration reaching very pronounced significance at ethanol concentrations above 10 %. Correspondingly fluorescence (Figure 3) was essentially constant whatever the ethanol concentration in spite of dramatically decreasing corresponding live cell count according to plate count (Figure 5) and percentage of live cells according to the live/dead staining (Figure 6) whereas luminescence dropped dramatically essentially corresponding to the dramatic drop in plate count (Figure 5) and the percentage of live cells (Figure 6) with increased ethanol concentration.

The effect of serum complement on the growth and death of *E. coli* is shown in Figures 7 to 9. Fluorescence (Figure 7) and luminescence (Figure 8) are shown before (squares) and after (circles) incubation for 90 minutes with serum complement. Fluorescence (Figure 7) is slightly increased, during incubation regardless of the concentration of serum, whereas luminescence (Figure 8) decreases during incubation with increasing serum concentration. The decrease of luminescence during incubation with increasing concentrations of serum correlates clearly with the percentage of cells alive after incubation (Figure 9).

L3

CLAIMS

1. A method to enable the assessment of the growth rate and death rate of a micro-organism within a chosen time period in an environment of interest **characterised** in that

a) at least two reporter genes are introduced into said micro-organism, wherein the reporter genes used code for luminescent and/or fluorescent products and within said time period and environment at least two said products of the following are produced:

i) an essentially stable product produced in a, within the environment of interest, essentially known proportion to the total amount of cells of said micro-organism that are or have been alive within said chosen time period,

ii) a product present in said environment of interest in an essentially known proportion to the amount of cells alive at any moment within said chosen time period, and

iii) an essentially stable product produced in a, within the environment of interest, essentially known proportion to the total amount of cells of the said micro-organism that have died within said chosen time period,

and which products can be measured through their luminescence and/or fluorescence;

b) the said micro-organism is incubated within the environment of interest and said luminescence and/or fluorescence is detected after said chosen time period, and

c) the growth and death rate of the said micro-organism is assessed based on at least two of the following:

i) the known proportion of luminescence or fluorescence to the amount of cells alive after any said chosen time period,

ii) the known proportion of luminescence or fluorescence to the total amount of cells that are or have been alive within any said chosen time period, and

iii) the known proportion of luminescence or fluorescence to the total amount of cells that have died within any said chosen time period.

2. The method according to claim 1 **characterised** in that said micro-organism is a gram negative bacteria, e.g. *Escherichia coli*.

3. The method according to claim 1 or 2 **characterised** in that

a) one reporter gene coding for a luminescent product is luciferase, which is used for the determination of amount of cells alive at any moment within said chosen time period, and

b) another reporter gene coding for a fluorescent product is green fluorescent protein (GFP), which is used for the determination of total amount of cells of said micro-organism that are or have been alive within said chosen time period.

4. The method according to claim 1 or 2 **characterised** in that said reporter genes are introduced into said micro-organism in a plasmid.

5. A method according to the methods of claim 3 and 4 **characterised** in that said plasmid is pGFP+luc* (Figure 1 and 2a–2f).

ABSTRACT

A method to enable the assessment of the growth rate and death rate of a micro-organism within a chosen time period in an environment of interest. The method is characterised in that

a) two reporter genes are introduced to said micro-organism wherein, the reporter genes used code for luminescent and/or fluorescent products and at least two of the following products: an essentially stable product produced in an essentially known proportion to the total amount of cells of said micro-organism that are or have been alive within said chosen time period; a product present in an essentially known proportion to the amount of cells alive at any moment within said chosen time period; and an essentially stable product produced in an essentially known proportion to the total amount of cells of the said micro-organism that have died within said chosen time period, and said products can be measured through their luminescence and/or fluorescence;

b) the said micro-organism is incubated and said luminescence and/or fluorescence is detected after said chosen time periods, and

c) the growth and death rate of the said micro-organism is assessed based on at least two of the following: the known proportion of luminescence or fluorescence to the amount of cells alive after any said chosen time period; the known proportion of luminescence or fluorescence to the total amount of cells that are or have been alive within any said chosen time period; and the known proportion of luminescence or fluorescence to the total amount of cells that have died within any said chosen time period.

L5

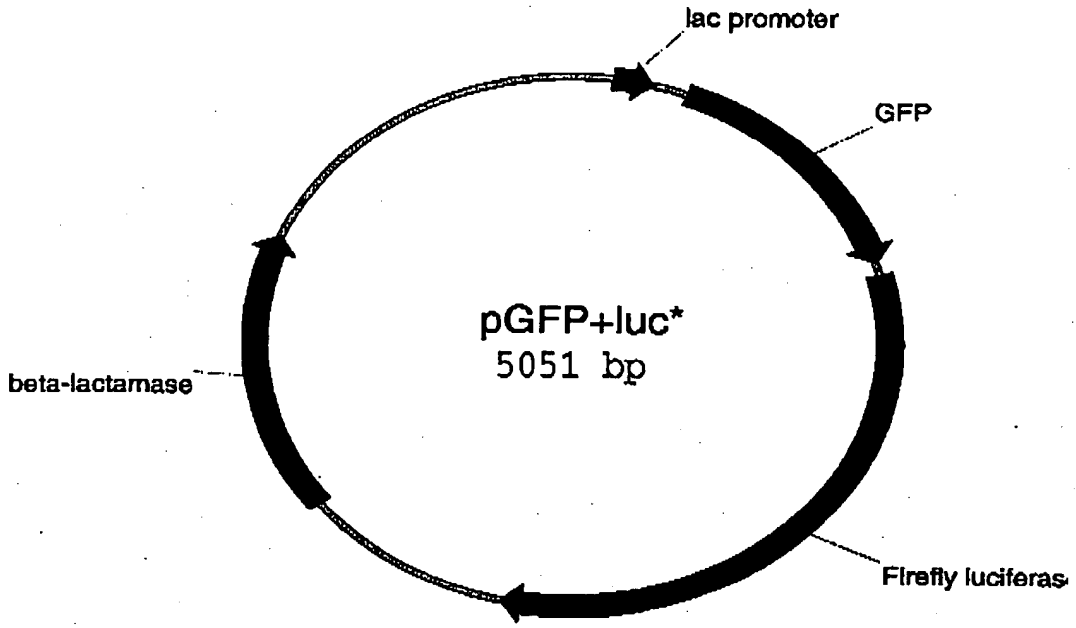
lac promoter
GFP
pGFP+luc*
5051 bp
beta-lactamase
Firefly luciferas

Figure 1

```
   1  AGCGCCCAAT ACGCAAACCG CCTCTCCCCG CGCGTTGGCC GATTCATTAA
      TCGCGGGTTA TGCGTTTGGC GGAGAGGGGC GCGCAACCGG CTAAGTAATT

  51  TGCAGCTGGC ACGACAGGTT TCCCGACTGG AAAGCGGGCA GTGAGCGCAA
      ACGTCGACCG TGCTGTCCAA AGGGCTGACC TTTCGCCCGT CACTCGCGTT

 101  CGCAATTAAT GTGAGTTAGC TCACTCATTA GGCACCCCAG GCTTTACACT
      GCGTTAATTA CACTCAATCG AGTGAGTAAT CCGTGGGGTC CGAAATGTGA

 151  TTATGCTTCC GGCTCGTATG TTGTGTGGAA TTGTGAGCGG ATAACAATTT
      AATACGAAGG CCGAGCATAC AACACACCTT AACACTCGCC TATTGTTAAA

 201  CACACAGGAA ACAGCTATGA CCATGATTAC GCCAAGCTTG CATGCCTGCA
      GTGTGTCCTT TGTCGATACT GGTACTAATG CGGTTCGAAC GTACGGACGT

 251  GGTCGACTCT AGAGGATCCC CGGGTACCGG TCGCCACCAT GGTGAGCAAG
      CCAGCTGAGA TCTCCTAGGG GCCCATGGCC AGCGGTGGTA CCACTCGTTC

 301  GGCGAGGAGC TGTTCACCGG GGTGGTGCCC ATCCTGGTCG AGCTGGACGG
      CCGCTCCTCG ACAAGTGGCC CCACCACGGG TAGGACCAGC TCGACCTGCC

 351  CGACGTAAAC GGCCACAAGT TCAGCGTGTC CGGCGAGGGC GAGGGCGATG
      GCTGCATTTG CCGGTGTTCA AGTCGCACAG GCCGCTCCCG CTCCCGCTAC

 401  CCACCTACGG CAAGCTGACC CTGAAGTTCA TCTGCACCAC CGGCAAGCTG
      GGTGGATGCC GTTCGACTGG GACTTCAAGT AGACGTGGTG GCCGTTCGAC

 451  CCCGTGCCCT GGCCCACCCT CGTGACCACC CTGACCTACG GCGTGCAGTG
      GGGCACGGGA CCGGGTGGGA GCACTGGTGG GACTGGATGC CGCACGTCAC

 501  CTTCAGCCGC TACCCCGACC ACATGAAGCA GCACGACTTC TTCAAGTCCG
      GAAGTCGGCG ATGGGGCTGG TGTACTTCGT CGTGCTGAAG AAGTTCAGGC

 551  CCATGCCCGA AGGCTACGTC CAGGAGCGCA CCATCTTCTT CAAGGACGAC
      GGTACGGGCT TCCGATGCAG GTCCTCGCGT GGTAGAAGAA GTTCCTGCTG

 601  GGCAACTACA AGACCCGCGC CGAGGTGAAG TTCGAGGGCG ACACCCTGGT
      CCGTTGATGT TCTGGGCGCG GCTCCACTTC AAGCTCCCGC TGTGGGACCA

 651  GAACCGCATC GAGCTGAAGG GCATCGACTT CAAGGAGGAC GGCAACATCC
      CTTGGCGTAG CTCGACTTCC CGTAGCTGAA GTTCCTCCTG CCGTTGTAGG

 701  TGGGGCACAA GCTGGAGTAC AACTACAACA GCCACAACGT CTATATCATG
      ACCCCGTGTT CGACCTCATG TTGATGTTGT CGGTGTTGCA GATATAGTAC

 751  GCCGACAAGC AGAAGAACGG CATCAAGGTG AACTTCAAGA TCCGCCACAA
      CGGCTGTTCG TCTTCTTGCC GTAGTTCCAC TTGAAGTTCT AGGCGGTGTT

 801  CATCGAGGAC GGCAGCGTGC AGCTCGCCGA CCACTACCAG CAGAACACCC
      GTAGCTCCTG CCGTCGCACG TCGAGCGGCT GGTGATGGTC GTCTTGTGGG

 851  CCATCGGCGA CGGCCCCGTG CTGCTGCCCG ACAACCACTA CCTGAGCACC
      GGTAGCCGCT GCCGGGGCAC GACGACGGGC TGTTGGTGAT GGACTCGTGG

 901  CAGTCCGCCC TGAGCAAAGA CCCCAACGAG AAGCGCGATC ACATGGTCCT
      GTCAGGCGGG ACTCGTTTCT GGGGTTGCTC TTCGCGCTAG TGTACCAGGA

 951  GCTGGAGTTC GTGACCGCCG CCGGGATCAC TCTCGGCATG GACGAGCTGT
      CGACCTCAAG CACTGGCGGC GGCCCTAGTG AGAGCCGTAC CTGCTCGACA
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Figure 2a

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1001  ACAAGTAAAG CGGCCGCTCT AGAACTAGTG GATCCCCCGT ACCATGGAAG
      TGTTCATTTC GCCGGCGAGA TCTTGATCAC CTAGGGGGCA TGGTACCTTC

1051  ACGCCAAAAA CATAAAGAAA GGCCCGGCGC CATTCTATCC GCTAGAGGAT
      TGCGGTTTTT GTATTTCTTT CCGGGCCGCG GTAAGATAGG CGATCTCCTA

1101  GGAACCGCTG GAGAGCAACT GCATAAGGCT ATGAAGAGAT ACGCCCTGGT
      CCTTGGCGAC CTCTCGTTGA CGTATTCCGA TACTTCTCTA TGCGGGACCA

1151  TCCTGGAACA ATTGCTTTTA CAGATGCACA TATCGAGGTG AACATCACGT
      AGGACCTTGT TAACGAAAAT GTCTACGTGT ATAGCTCCAC TTGTAGTGCA

1201  ACGCGGAATA CTTCGAAATG TCCGTTCGGT TGGCAGAAGC TATGAAACGA
      TGCGCCTTAT GAAGCTTTAC AGGCAAGCCA ACCGTCTTCG ATACTTTGCT

1251  TATGGGCTGA ATACAAATCA CAGAATCGTC GTATGCAGTG AAAACTCTCT
      ATACCCGACT TATGTTTAGT GTCTTAGCAG CATACGTCAC TTTTGAGAGA

1301  TCAATTCTTT ATGCCGGTGT TGGGCGCGTT ATTTATCGGA GTTGCAGTTG
      AGTTAAGAAA TACGGCCACA ACCCGCGCAA TAAATAGCCT CAACGTCAAC

1351  CGCCCGCGAA CGACATTTAT AATGAACGTG AATTGCTCAA CAGTATGAAC
      GCGGGCGCTT GCTGTAAATA TTACTTGCAC TTAACGAGTT GTCATACTTG

1401  ATTTCGCAGC CTACCGTAGT GTTTGTTTCC AAAAAGGGGT TGCAAAAAAT
      TAAAGCGTCG GATGGCATCA CAAACAAAGG TTTTTCCCCA ACGTTTTTTA

1451  TTTGAACGTG CAAAAAAAAT TACCAATAAT CCAGAAAATT ATTATCATGG
      AAACTTGCAC GTTTTTTTTA ATGGTTATTA GGTCTTTTAA TAATAGTACC

1501  ATTCTAAAAC GGATTACCAG GGATTTCAGT CGATGTACAC GTTCGTCACA
      TAAGATTTTG CCTAATGGTC CCTAAAGTCA GCTACATGTG CAAGCAGTGT

1551  TCTCATCTAC CTCCCGGTTT TAATGAATAC GATTTTGTAC CAGAGTCCTT
      AGAGTAGATG GAGGGCCAAA ATTACTTATG CTAAAACATG GTCTCAGGAA

1601  TGATCGTGAC AAAACAATTG CACTGATAAT GAACTCCTCT GGATCTACTG
      ACTAGCACTG TTTTGTTAAC GTGACTATTA CTTGAGGAGA CCTAGATGAC

1651  GGTTACCTAA GGGTGTGGCC CTTCCGCATA GAACTGCCTG CGTCAGATTC
      CCAATGGATT CCCACACCGG GAAGGCGTAT CTTGACGGAC GCAGTCTAAG

1701  TCGCATGCCA GAGATCCTAT TTTTGGCAAT CAAATCATTC CGGATACTGC
      AGCGTACGGT CTCTAGGATA AAAACCGTTA GTTTAGTAAG GCCTATGACG

1751  GATTTTAAGT GTTGTTCCAT TCCATCACGG TTTTGGAATG TTTACTACAC
      CTAAAATTCA CAACAAGGTA AGGTAGTGCC AAAACCTTAC AAATGATGTG

1801  TCGGATATTT GATATGTGGA TTTCGAGTCG TCTTAATGTA TAGATTTGAA
      AGCCTATAAA CTATACACCT AAAGCTCAGC AGAATTACAT ATCTAAACTT

1851  GAAGAGCTGT TTTTACGATC CCTTCAGGAT TACAAAATTC AAAGTGCGTT
      CTTCTCGACA AAAATGCTAG GGAAGTCCTA ATGTTTTAAG TTTCACGCAA

1901  GCTAGTACCA ACCCTATTTT CATTCTTCGC CAAAAGCACT CTGATTGACA
      CGATCATGGT TGGGATAAAA GTAAGAAGCG GTTTTCGTGA GACTAACTGT

1951  AATACGATTT ATCTAATTTA CACGAAATTG CTTCTGGGGG CGCACCTCTT
      TTATGCTAAA TAGATTAAAT GTGCTTTAAC GAAGACCCCC GCGTGGAGAA
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Figure 2b

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2001  TCGAAAGAAG TCGGGGAAGC GGTTGCAAAA CGCTTCCATC TTCCAGGGAT
      AGCTTTCTTC AGCCCCTTCG CCAACGTTTT GCGAAGGTAG AAGGTCCCTA

2051  ACGACAAGGA TATGGGCTCA CTGAGACTAC ATCAGCTATT CTGATTACAC
      TGCTGTTCCT ATACCCGAGT GACTCTGATG TAGTCGATAA GACTAATGTG

2101  CCGAGGGGGA TGATAAACCG GGCGCGGTCG GTAAAGTTGT TCCATTTTTT
      GGCTCCCCCT ACTATTTGGC CCGCGCCAGC CATTTCAACA AGGTAAAAAA

2151  GAAGCGAAGG TTGTGGATCT GGATACCGGG AAAACGCTGG GCGTTAATCA
      CTTCGCTTCC AACACCTAGA CCTATGGCCC TTTTGCGACC CGCAATTAGT

2201  GAGAGGCGAA TTATGTGTCA GAGGACCTAT GATTATGTCC GGTTATGTAA
      CTCTCCGCTT AATACACAGT CTCCTGGATA CTAATACAGG CCAATACATT

2251  ACAATCCGGA AGCGACCAAC GCCTTGATTG ACAAGGATGG ATGGCTACAT
      TGTTAGGCCT TCGCTGGTTG CGGAACTAAC TGTTCCTACC TACCGATGTA

2301  TCTGGAGACA TAGCTTACTG GGACGAAGAC GAACACTTCT TCATAGTTGA
      AGACCTCTGT ATCGAATGAC CCTGCTTCTG CTTGTGAAGA AGTATCAACT

2351  CCGCTTGAAG TCTTTAATTA AATACAAAGG ATACCAGGTG GCCCCCGCTG
      GGCGAACTTC AGAAATTAAT TTATGTTTCC TATGGTCCAC CGGGGGCGAC

2401  AATTGGAGTC GATATTGTTA CAACACCCCA ACATCTTCGA CGCGGGCGTG
      TTAACCTCAG CTATAACAAT GTTGTGGGGT TGTAGAAGCT GCGCCCGCAC

2451  GCAGGTCTTC CCGACGATGA CGCCGGTGAA CTTCCCGCCG CCGTTGTTGT
      CGTCCAGAAG GGCTGCTACT GCGGCCACTT GAAGGGCGGC GGCAACAACA

2501  TTTGGAGCAC GGAAAGACGA TGACGGAAAA AGAGATCGTG GATTACGTCG
      AAACCTCGTG CCTTTCTGCT ACTGCCTTTT TCTCTAGCAC CTAATGCAGC

2551  CCAGTCAAGT AACAACCGCC AAAAAGTTGC GCGGAGGAGT TGTGTTTGTG
      GGTCAGTTCA TTGTTGGCGG TTTTTCAACG CGCCTCCTCA ACACAAACAC

2601  GACGAAGTAC CGAAAGGTCT TACCGGAAAA CTCGACGCAA GAAAAATCAG
      CTGCTTCATG GCTTTCCAGA ATGGCCTTTT GAGCTGCGTT CTTTTTAGTC

2651  AGAGATCCTC ATAAAGGCCA AGAAGGGCGG AAAGTCCAAA TTGTAAAATG
      TCTCTAGGAG TATTTCCGGT TCTTCCCGCC TTTCAGGTTT AACATTTTAC

2701  TAACTGTATT CAGCGATGAC GAAATTCTTA GCTATTGTAA TACTCTAGGG
      ATTGACATAA GTCGCTACTG CTTTAAGAAT CGATAACATT ATGAGATCCC

2751  GCTGCAGGAA TTCGATATCA AGCTTATCGA TACCGTCGAC CTCGAGGGGG
      CGACGTCCTT AAGCTATAGT TCGAATAGCT ATGGCAGCTG GAGCTCCCCC

2801  GGCCCTTTCG TCTCGCGCGT TTCGGTGATG ACGGTGAAAA CCTCTGACAC
      CCGGGAAAGC AGAGCGCGCA AAGCCACTAC TGCCACTTTT GGAGACTGTG

2851  ATGCAGCTCC CGGAGACGGT CACAGCTTGT CTGTAAGCGG ATGCCGGGAG
      TACGTCGAGG GCCTCTGCCA GTGTCGAACA GACATTCGCC TACGGCCCTC

2901  CAGACAAGCC CGTCAGGGCG CGTCAGCGGG TGTTGGCGGG TGTCGGGGCT
      GTCTGTTCGG GCAGTCCCGC GCAGTCGCCC ACAACCGCCC ACAGCCCCGA

2951  GGCTTAACTA TGCGGCATCA GAGCAGATTG TACTGAGAGT GCACCATATG
      CCGAATTGAT ACGCCGTAGT CTCGTCTAAC ATGACTCTCA CGTGGTATAC
```

Figure 2c

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3001  CGGTGTGAAA TACCGCACAG ATGCGTAAGG AGAAAATACC GCATCAGGCG
      GCCACACTTT ATGGCGTGTC TACGCATTCC TCTTTTATGG CGTAGTCCGC

3051  GCCTTAAGGG CCTCGTGATA CGCCTATTTT TATAGGTTAA TGTCATGATA
      CGGAATTCCC GGAGCACTAT GCGGATAAAA ATATCCAATT ACAGTACTAT

3101  ATAATGGTTT CTTAGACGTC AGGTGGCACT TTTCGGGGAA ATGTGCGCGG
      TATTACCAAA GAATCTGCAG TCCACCGTGA AAAGCCCCTT TACACGCGCC

3151  AACCCCTATT TGTTTATTTT TCTAAATACA TTCAAATATG TATCCGCTCA
      TTGGGGATAA ACAAATAAAA AGATTTATGT AAGTTTATAC ATAGGCGAGT

3201  TGAGACAATA ACCCTGATAA ATGCTTCAAT AATATTGAAA AAGGAAGAGT
      ACTCTGTTAT TGGGACTATT TACGAAGTTA TTATAACTTT TTCCTTCTCA

3251  ATGAGTATTC AACATTTCCG TGTCGCCCTT ATTCCCTTTT TTGCGGCATT
      TACTCATAAG TTGTAAAGGC ACAGCGGGAA TAAGGGAAAA AACGCCGTAA

3301  TTGCCTTCCT GTTTTTGCTC ACCCAGAAAC GCTGGTGAAA GTAAAAGATG
      AACGGAAGGA CAAAAACGAG TGGGTCTTTG CGACCACTTT CATTTTCTAC

3351  CTGAAGATCA GTTGGGTGCA CGAGTGGGTT ACATCGAACT GGATCTCAAC
      GACTTCTAGT CAACCCACGT GCTCACCCAA TGTAGCTTGA CCTAGAGTTG

3401  AGCGGTAAGA TCCTTGAGAG TTTTCGCCCC GAAGAACGTT TTCCAATGAT
      TCGCCATTCT AGGAACTCTC AAAAGCGGGG CTTCTTGCAA AAGGTTACTA

3451  GAGCACTTTT AAAGTTCTGC TATGTGGCGC GGTATTATCC CGTATTGACG
      CTCGTGAAAA TTTCAAGACG ATACACCGCG CCATAATAGG GCATAACTGC

3501  CCGGGCAAGA GCAACTCGGT CGCCGCATAC ACTATTCTCA GAATGACTTG
      GGCCCGTTCT CGTTGAGCCA GCGGCGTATG TGATAAGAGT CTTACTGAAC

3551  GTTGAGTACT CACCAGTCAC AGAAAAGCAT CTTACGGATG GCATGACAGT
      CAACTCATGA GTGGTCAGTG TCTTTTCGTA GAATGCCTAC CGTACTGTCA

3601  AAGAGAATTA TGCAGTGCTG CCATAACCAT GAGTGATAAC ACTGCGGCCA
      TTCTCTTAAT ACGTCACGAC GGTATTGGTA CTCACTATTG TGACGCCGGT

3651  ACTTACTTCT GACAACGATC GGAGGACCGA AGGAGCTAAC CGCTTTTTTG
      TGAATGAAGA CTGTTGCTAG CCTCCTGGCT TCCTCGATTG GCGAAAAAAC

3701  CACAACATGG GGGATCATGT AACTCGCCTT GATCGTTGGG AACCGGAGCT
      GTGTTGTACC CCCTAGTACA TTGAGCGGAA CTAGCAACCC TTGGCCTCGA

3751  GAATGAAGCC ATACCAAACG ACGAGCGTGA CACCACGATG CCTGTAGCAA
      CTTACTTCGG TATGGTTTGC TGCTCGCACT GTGGTGCTAC GGACATCGTT

3801  TGGCAACAAC GTTGCGCAAA CTATTAACTG GCGAACTACT TACTCTAGCT
      ACCGTTGTTG CAACGCGTTT GATAATTGAC CGCTTGATGA ATGAGATCGA

3851  TCCCGGCAAC AATTAATAGA CTGGATGGAG GCGGATAAAG TTGCAGGACC
      AGGGCCGTTG TTAATTATCT GACCTACCTC CGCCTATTTC AACGTCCTGG

3901  ACTTCTGCGC TCGGCCCTTC CGGCTGGCTG GTTTATTGCT GATAAATCTG
      TGAAGACGCG AGCCGGGAAG GCCGACCGAC CAAATAACGA CTATTTAGAC

3951  GAGCCGGTGA GCGTGGGTCT CGCGGTATCA TTGCAGCACT GGGGCCAGAT
      CTCGGCCACT CGCACCCAGA GCGCCATAGT AACGTCGTGA CCCCGGTCTA
```

Figure 2d

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4001  GGTAAGCCCT CCCGTATCGT AGTTATCTAC ACGACGGGGA GTCAGGCAAC
      CCATTCGGGA GGGCATAGCA TCAATAGATG TGCTGCCCCT CAGTCCGTTG

4051  TATGGATGAA CGAAATAGAC AGATCGCTGA GATAGGTGCC TCACTGATTA
      ATACCTACTT GCTTTATCTG TCTAGCGACT CTATCCACGG AGTGACTAAT

4101  AGCATTGGTA ACTGTCAGAC CAAGTTTACT CATATATACT TTAGATTGAT
      TCGTAACCAT TGACAGTCTG GTTCAAATGA GTATATATGA AATCTAACTA

4151  TTAAAACTTC ATTTTTAATT TAAAAGGATC TAGGTGAAGA TCCTTTTTGA
      AATTTTGAAG TAAAAATTAA ATTTTCCTAG ATCCACTTCT AGGAAAAACT

4201  TAATCTCATG ACCAAAATCC CTTAACGTGA GTTTTCGTTC CACTGAGCGT
      ATTAGAGTAC TGGTTTTAGG GAATTGCACT CAAAAGCAAG GTGACTCGCA

4251  CAGACCCCGT AGAAAAGATC AAAGGATCTT CTTGAGATCC TTTTTTTCTG
      GTCTGGGGCA TCTTTTCTAG TTTCCTAGAA GAACTCTAGG AAAAAAAGAC

4301  CGCGTAATCT GCTGCTTGCA AACAAAAAAA CCACCGCTAC CAGCGGTGGT
      GCGCATTAGA CGACGAACGT TTGTTTTTTT GGTGGCGATG GTCGCCACCA

4351  TTGTTTGCCG GATCAAGAGC TACCAACTCT TTTTCCGAAG GTAACTGGCT
      AACAAACGGC CTAGTTCTCG ATGGTTGAGA AAAAGGCTTC CATTGACCGA

4401  TCAGCAGAGC GCAGATACCA AATACTGTCC TTCTAGTGTA GCCGTAGTTA
      AGTCGTCTCG CGTCTATGGT TTATGACAGG AAGATCACAT CGGCATCAAT

4451  GGCCACCACT TCAAGAACTC TGTAGCACCG CCTACATACC TCGCTCTGCT
      CCGGTGGTGA AGTTCTTGAG ACATCGTGGC GGATGTATGG AGCGAGACGA

4501  AATCCTGTTA CCAGTGGCTG CTGCCAGTGG CGATAAGTCG TGTCTTACCG
      TTAGGACAAT GGTCACCGAC GACGGTCACC GCTATTCAGC ACAGAATGGC

4551  GGTTGGACTC AAGACGATAG TTACCGGATA AGGCGCAGCG GTCGGGCTGA
      CCAACCTGAG TTCTGCTATC AATGGCCTAT TCCGCGTCGC CAGCCCGACT

4601  ACGGGGGGTT CGTGCACACA GCCCAGCTTG GAGCGAACGA CCTACACCGA
      TGCCCCCCAA GCACGTGTGT CGGGTCGAAC CTCGCTTGCT GGATGTGGCT

4651  ACTGAGATAC CTACAGCGTG AGCTATGAGA AAGCGCCACG CTTCCCGAAG
      TGACTCTATG GATGTCGCAC TCGATACTCT TTCGCGGTGC GAAGGGCTTC

4701  GGAGAAAGGC GGACAGGTAT CCGGTAAGCG GCAGGGTCGG AACAGGAGAG
      CCTCTTTCCG CCTGTCCATA GGCCATTCGC CGTCCCAGCC TTGTCCTCTC

4751  CGCACGAGGG AGCTTCCAGG GGGAAACGCC TGGTATCTTT ATAGTCCTGT
      GCGTGCTCCC TCGAAGGTCC CCCTTTGCGG ACCATAGAAA TATCAGGACA

4801  CGGGTTTCGC CACCTCTGAC TTGAGCGTCG ATTTTTGTGA TGCTCGTCAG
      GCCCAAAGCG GTGGAGACTG AACTCGCAGC TAAAAACACT ACGAGCAGTC

4851  GGGGGCGGAG CCTATGGAAA AACGCCAGCA ACGCGGCCTT TTTACGGTTC
      CCCCCGCCTC GGATACCTTT TTGCGGTCGT TGCGCCGGAA AAATGCCAAG

4901  CTGGCCTTTT GCTGGCCTTT TGCTCACATG TTCTTTCCTG CGTTATCCCC
      GACCGGAAAA CGACCGGAAA ACGAGTGTAC AAGAAAGGAC GCAATAGGGG

4951  TGATTCTGTG GATAACCGTA TTACCGCCTT TGAGTGAGCT GATACCGCTC
      ACTAAGACAC CTATTGGCAT AATGGCGGAA ACTCACTCGA CTATGGCGAG
```

Figure 2e

```
5001  GCCGCAGCCG AACGACCGAG CGCAGCGAGT CAGTGAGCGA GGAAGCGGAA
      CGGCGTCGGC TTGCTGGCTC GCGTCGCTCA GTCACTCGCT CCTTCGCCTT

5051  G
      C
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Figure 2f

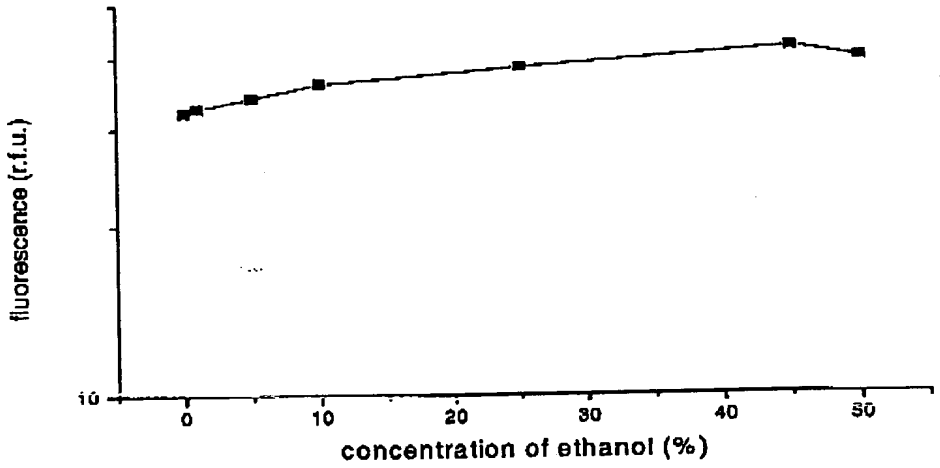

Figure 3

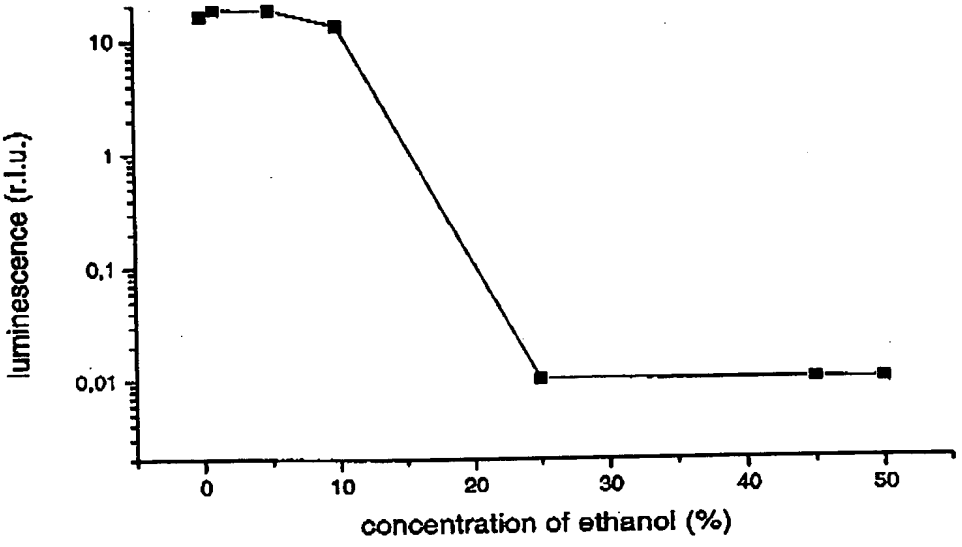

Figure 4

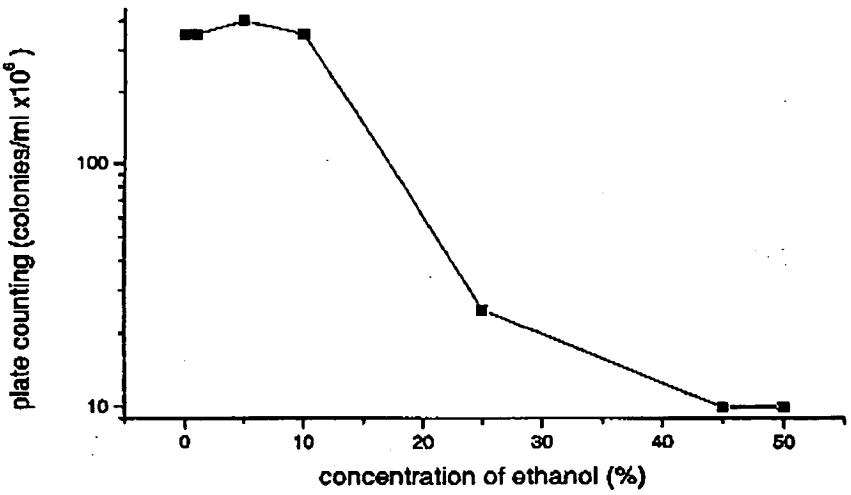

Figure 5

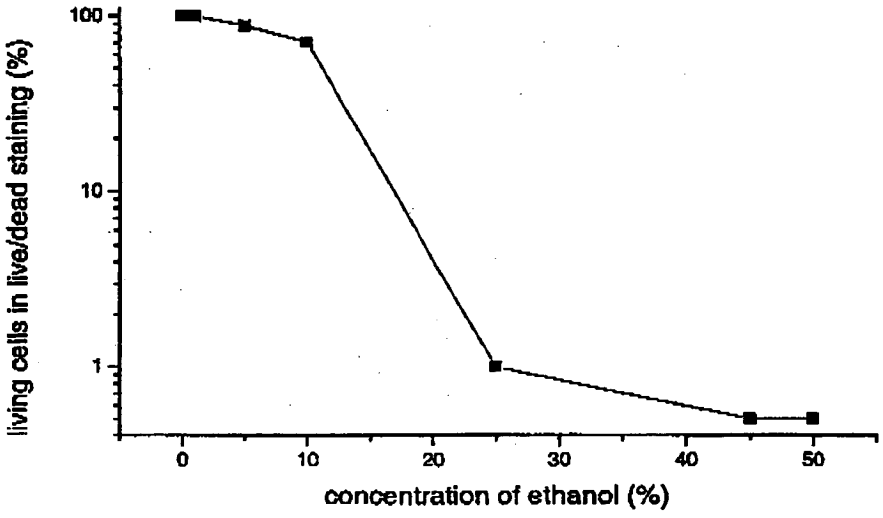

Figure 6

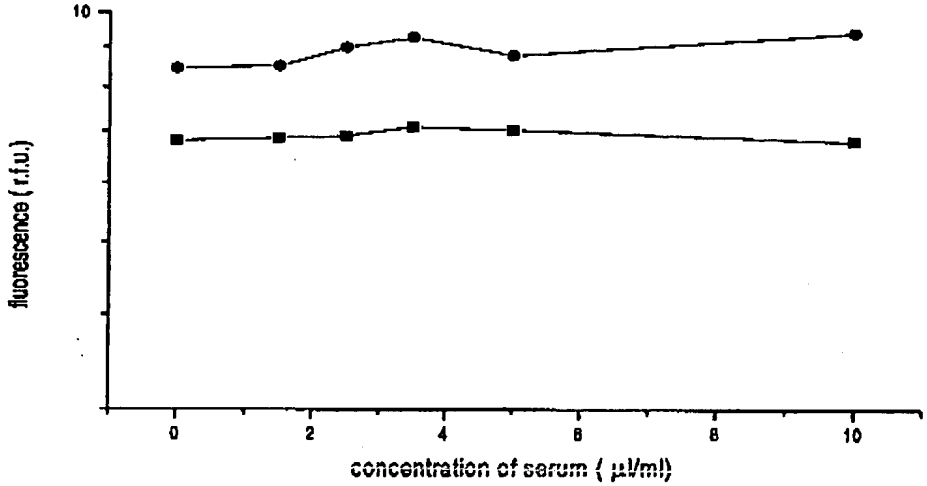

Figure 7

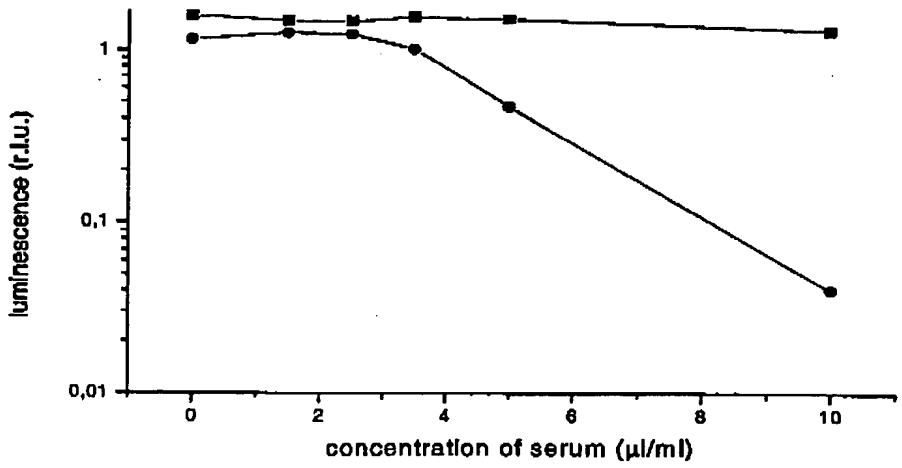

Figure 8

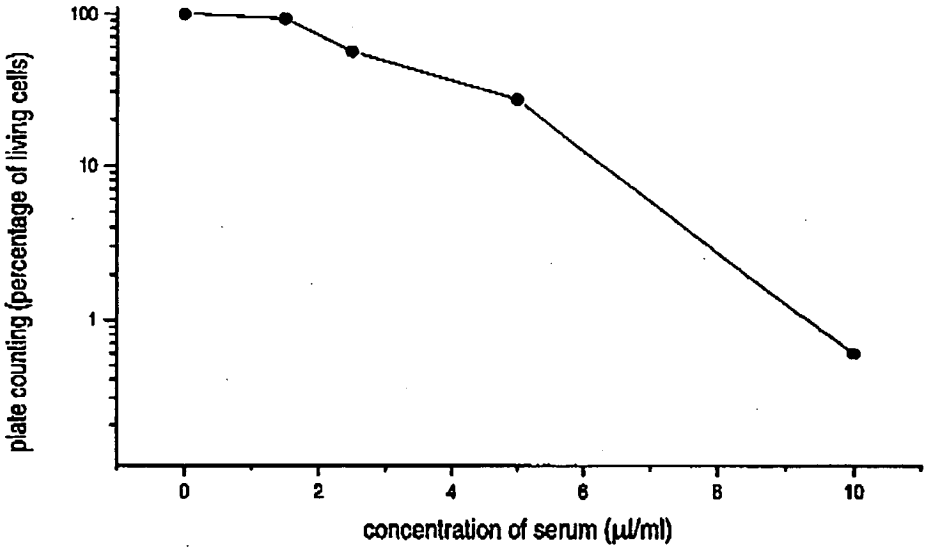
100
10
1
plate counting (percentage of living cells)
0
2
4
6
8
10
concentration of serum (µl/ml)

Figure 9